Development of a Packed-Bed Adsorption Model With Predictive Capabilities

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Continuous carbon-dioxide removal from the cabin air is a critical life-support system function on manned space missions. On the *International Space Station*, the carbon-dioxide removal assembly design must maintain a cabin carbon-dioxide concentration of less than 0.7 percent in atmospheric pressure. Several additional constraints are placed upon the design: it must function quietly and extremely reliably in microgravity; exist and operate within tight mass, volume, and power envelopes; and must produce high-purity carbon dioxide suitable for subsequent processing that will extract and return oxygen to the cabin. Furthermore, it must use a minimal amount of consumables to reduce the costs and reliability considerations of logistics.

The carbon-dioxide separation technology chosen for the U.S. portion of the space station—based on selective adsorption equilibria—is called "four-bed molecular sieve," and is being designed and built by the Allied Signal Corporation under subcontract to Boeing.[1] Four adsorbent beds (two desiccating, two carbon-dioxide removing) operate in a thermal/vacuum swing cycle. A diurnal cycle is also imposed on the operation. The unit produces a carbon-dioxide stream of 99-percent purity. The removing beds (which contain a 5A zeolite) use a honeycomb heater core to provide the energy for desorption.

A half-cycle schematic (fig. 97) illustrates the four-bed molecular sieve carbon-dioxide removal assembly for the U.S. Laboratory and Habitation modules on the *International Space*

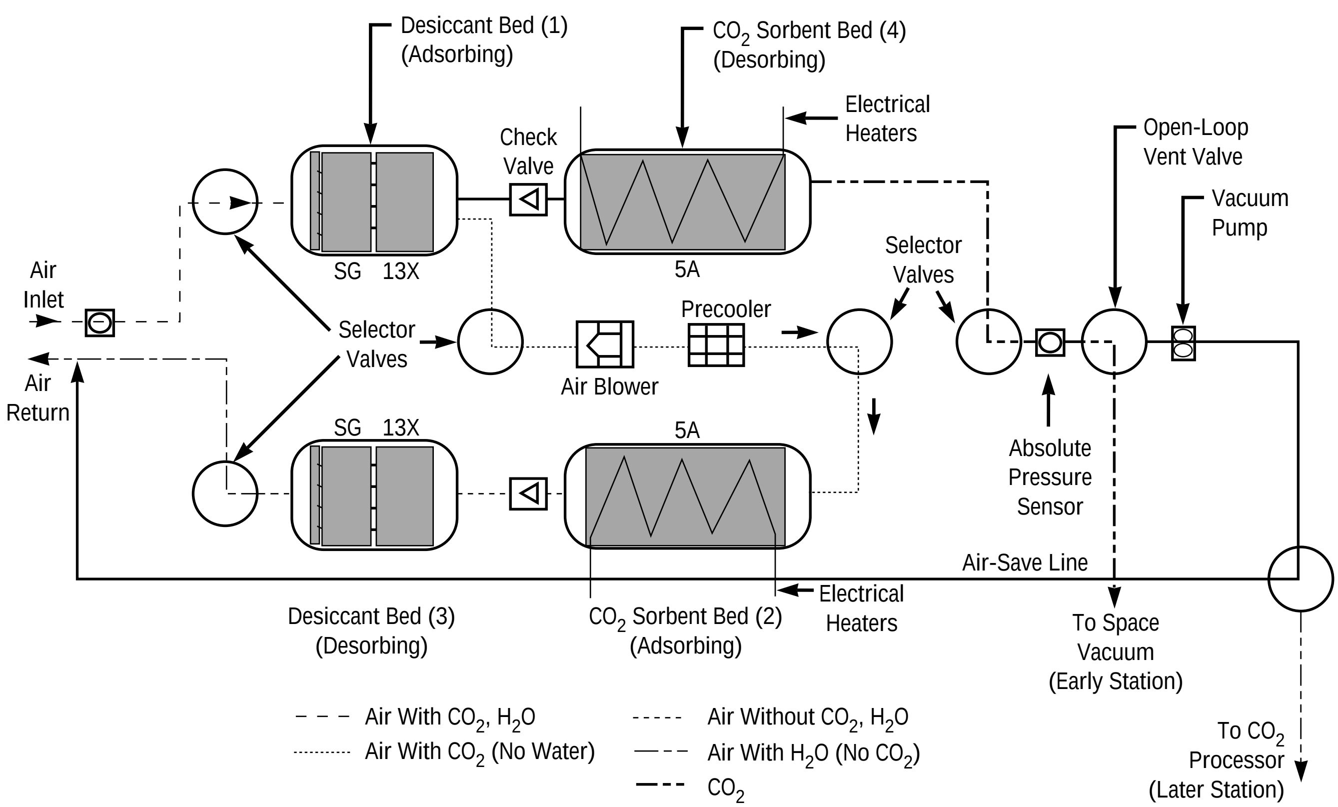

FIGURE 97.—Half-cycle schematic of the four-bed molecular sieve carbon-dioxide removal assembly.

Station. Inlet air is first drawn through the desiccant bed, after which it is directed through a precooler and the carbon-dioxide adsorbent bed. The warm air then desorbs water from the other desiccant bed and returns, humidified, to the cabin. Meanwhile, carbon dioxide is desorbed from the regenerating adsorbent bed and is released to space or stored for reduction and oxygen generation. Nitrogen and oxygen that desorb ahead of the carbon dioxide are returned to the cabin via the air-save line.

In order to predict the consequences of processor design changes, tune the processor's operating conditions and cycling schedule, and ascertain the effects of its operation on the cabin environment, the four-bed processor is being modeled and simulated using a finite-difference method. The honeycombs present in the carbon-dioxide removing beds introduce a significant amount of channeling, and necessitate the use of a two-dimensional (axial and radial) model. Verification testing has been conducted on laboratory-scale packed beds to determine empirically lumped mass-transfer coefficients and to verify and refine the computer models. Researchers have also undertaken a study of the multicomponent equilibria important to the processor's operation and, in particular, the co-adsorption of water, nitrogen, and carbon dioxide on the materials used for the separation. Inclusion of these and other significant phenomena present in the carbon-dioxide removal process are critical to the development of a computer model with the capability to predict processor operation when large changes are made in its configuration.

Researchers have successfully developed models of the packed sorbent beds in a stand-alone configuration.[2] The simulations and experimental results demonstrate the importance of incorporating the thermal effects of adsorption and the interactions between adsorbates, particularly nitrogen and carbon dioxide, in this processor. (Figure 98 illustrates the consequence of neglecting nitrogen on the simulation of packed-bed carbon-dioxide breakthrough.) Ongoing efforts are focused on the integration of the stand-alone models into an integrated model of the four-bed molecular sieve removal assembly.

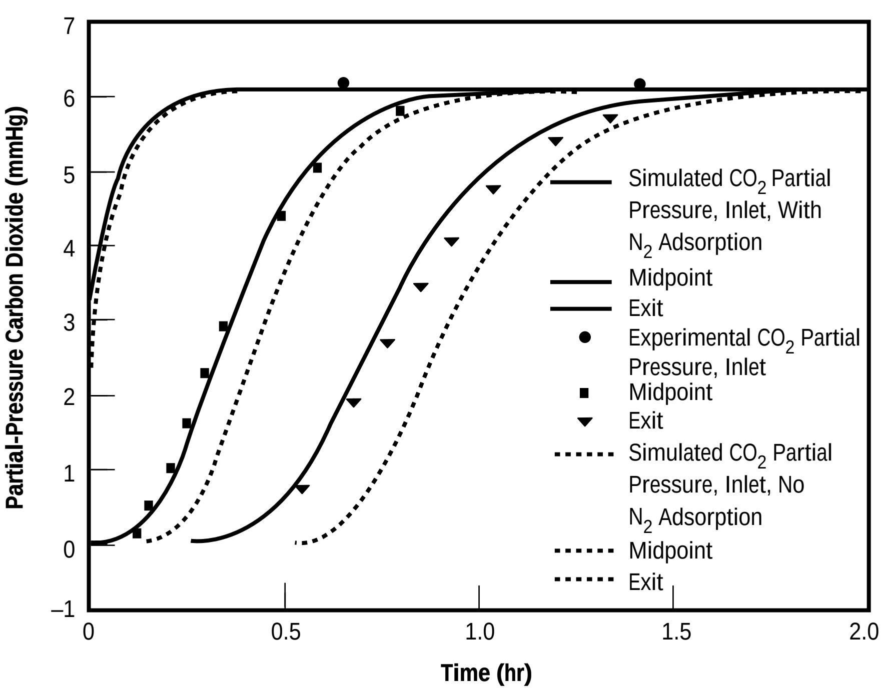

FIGURE 98.—Experimental and simulated carbon-dioxide breakthrough with and without nitrogen co-adsorption.

The model being developed in this effort is expected to enhance understanding of the carbon-dioxide removal assembly and facilitate the optimization of the system to address the design issues associated with meeting the severe requirements of such a separation system for space. It will provide a tool for investigation of alternative methods already in use in the U.S. shuttle and Russian Mir programs, and alternative designs under consideration aimed at maintaining a lower cabin carbon-dioxide concentration and involving kinetic adsorptive separations, resistance heating of sorbents, hydrophobic adsorbents, and other techniques. Commercial applications include the investigation and optimization of sorbent systems, used widely in the petroleum and gas-separation industries.

[1]Atmospheric Revitalization Subsystem Description. 1993. Boeing Corporation (NAS8–50000), D683–15003–1.

[2]Mohamadinejad, H., and Knox, J.C. 1994. Development and Verification Testing of a Hardware-Independent Molecular Sieve Model. Second International Conference on Life Support and Biosphere Sciences, Huntsville, Alabama.

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